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## FFT Measurement

FFT is used to compute the fast Fourier transform using analog input channels or math functions 1 + 2, 1 - 2, or 1 \* 2. FFT takes the digitized time record of the specified source and transforms it to the frequency domain. When the FFT function is selected, the FFT spectrum is plotted on the oscilloscope display as magnitude in dBV versus frequency. The readout for the horizontal axis changes from time to frequency (Hertz) and the vertical readout changes from volts to dB.

Use the FFT function to find crosstalk problems, to find distortion problems in analog waveforms caused by amplifier non-linearity, or for adjusting analog filters.

**FFT Units** 0 dBV is the amplitude of a 1 Vrms sinusoid. When the FFT source is channel 1 or channel 2 (or channel 3 or 4 on the 54624A), FFT units will be displayed in dBV when channel units is set to Volts and channel impedance is set to 1 M $\Omega$ .

For the 54640-series, FFT units will be displayed in dBm when channel units is set to Volts and channel impedance is set to 50 $\Omega$ . For the 54620-series, if you want the result to be in dBm, you must connect a 50 $\Omega$  load (10100C or equivalent) to the analog channel input, and then perform the following conversion:

$$\text{dBm} = \text{dBV} + 13.01$$

FFT units will be displayed as dB for all other FFT sources or when a source channel's units has been set to Amps.

**DC Value** The FFT computation produces a DC value that is incorrect. It does not take the offset at center screen into account. The DC value is not corrected in order to accurately represent frequency components near DC.

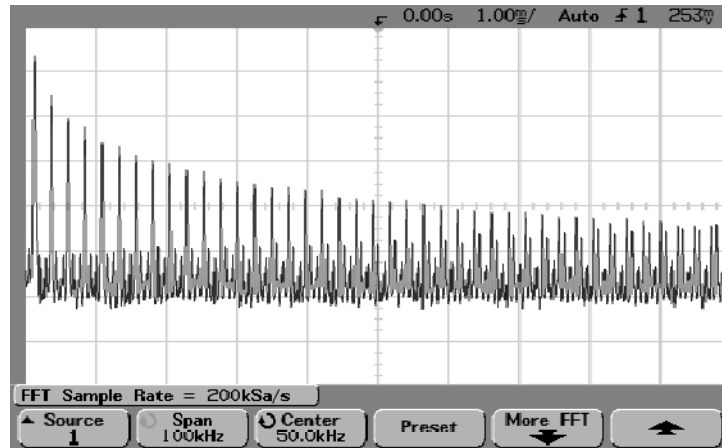
**Aliasing** When using FFTs, it is important to be aware of frequency aliasing. This requires that the operator have some knowledge as to what the frequency domain should contain, and also consider the effective sampling rate, frequency span, and oscilloscope vertical bandwidth when making FFT measurements. The FFT sample rate is displayed directly above the softkeys when the FFT menu is displayed.

Aliasing happens when there are frequency components in the signal higher than half the effective sample rate. Since the FFT spectrum is limited by this frequency, any higher components are displayed at a lower (aliased) frequency.

## Making Measurements

### FFT Measurement

The following figure illustrates aliasing. This is the spectrum of a 1 kHz square wave, which has many harmonics. The sample rate is set to 200 kSa/s, and the oscilloscope displays the spectrum. The displayed waveform shows the components of the input signal above the Nyquist frequency to be mirrored (aliased) on the display and reflected off the right edge.



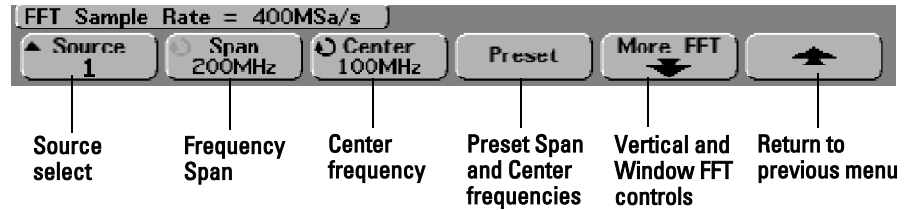
### Aliasing

Since the frequency span goes from  $\approx 0$  to the Nyquist frequency, the best way to prevent aliasing is to make sure that the frequency span is greater than the frequencies of significant energy present in the input signal.

**Spectral Leakage** The FFT operation assumes that the time record repeats. Unless there is an integral number of cycles of the sampled waveform in the record, a discontinuity is created at the end of the record. This is referred to as leakage. In order to minimize spectral leakage, windows that approach zero smoothly at the beginning and end of the signal are employed as filters to the FFT. The FFT menu provides three windows: Hanning, flattop, and rectangular. For more information on leakage, see Agilent Application Note 243, "The Fundamentals of Signal Analysis" (Agilent part number 5952-8898).

## FFT Operation

- 1 Press the **Math** key, press the **FFT** softkey, then press the **Settings** softkey to display the FFT menu.



**Source** selects the source for the FFT. The source can be any analog channel, or math functions  $1 + 2$ ,  $1 - 2$ , and  $1 * 2$ .

**Span** sets the overall width of the FFT spectrum that you see on the display (left graticule to right graticule). Divide span by 10 to calculate the number of Hertz per division. It is possible to set Span above the maximum available frequency, in which case the displayed spectrum will not take up the whole screen. Press the **Span** softkey, then turn the Entry knob to set the desired frequency span of the display.

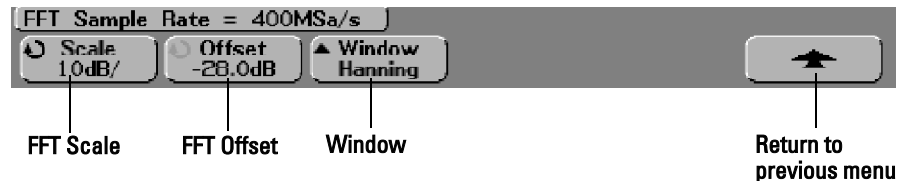
**Center** sets the FFT spectrum frequency represented at the center graticule on the display. It is possible to set the Center to values below half the span or above the maximum available frequency, in which case the displayed spectrum will not take up the whole screen. Press the **Center** softkey, then turn the Entry knob to set the desired center frequency of the display.

**Preset** sets the frequency Span and Center to values that will cause the entire available spectrum to be displayed. The maximum available frequency is half the effective FFT sample rate, which is a function of the time per division setting. The current FFT sample rate is displayed above the softkeys.

## Making Measurements

### FFT Measurement

- 2 Press the More FFT softkey to display additional FFT settings.



**Scale** allows you to set your own vertical scale factors for FFT expressed in dB/div (decibels/division). Press the **Scale** softkey, then turn the Entry knob to rescale your math function.

**Offset** allows you to set your own offset for the FFT. The offset value is in dB and is represented by the center graticule of the display. Press the **Offset** softkey, then turn the Entry knob to change the offset of your math function.

#### Scale and offset considerations

If you do not manually change the FFT scale or offset settings, when you turn the horizontal sweep speed knob, the span and center frequency settings will automatically change to allow optimum viewing of the full spectrum. If you do manually set scale or offset, turning the sweep speed knob will not change the span or center frequency settings, allowing you see better detail around a specific frequency. Pressing the FFT Preset softkey will automatically rescale the waveform and span and center will again automatically track the horizontal sweep speed setting.

**Window** selects a window to apply to your FFT input signal:

**Hanning** - window for making accurate frequency measurements or for resolving two frequencies that are close together.

**Flat Top** - window for making accurate amplitude measurements of frequency peaks.

**Rectangular** - good frequency resolution and amplitude accuracy, but use only where there will be no leakage effects. Use on self-windowing waveforms such as pseudo-random noise, impulses, sine bursts, and decaying sinusoids.

- 3 To make cursors measurements, press the **Cursors** key and set the **Source** softkey to **Math**.

Use the X1 and X2 cursors to measure frequency values and difference between two frequency values ( $\Delta X$ ). Use the Y1 and Y2 cursors to measure amplitude in dB and difference in amplitude ( $\Delta Y$ ).

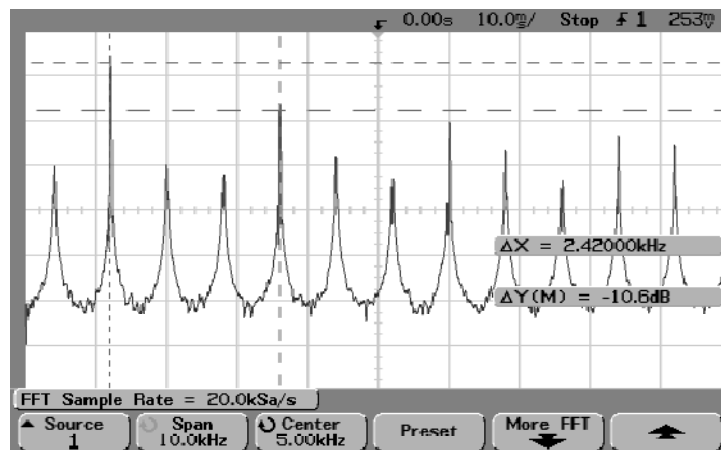
## Making Measurements

### FFT Measurement

- To make other measurements, press the **Quick Meas** key and set the **Source** softkey to **Math**.

You can make peak-to-peak, maximum, minimum, and average dB measurements on the FFT waveform. You can also find the frequency value at the first occurrence of the waveform maximum by using the X at Max measurement.

The following FFT spectrum was obtained by connecting the front panel Probe Comp signal (~1.2 kHz from 54620-series) to channel 1. Set sweep speed to 10 ms/div, vertical sensitivity to 1 V/div, Units/div to 10 dB, Offset to -28.0 dB, Center frequency to 5.00 kHz, frequency Span to 10.0 kHz, and window to Hanning.



#### FFT measurements

##### FFT Measurement Hints

It is easiest to view FFTs with Vectors set to On. The Vector display mode is set in the Display menu.

The number of points acquired for the FFT record 2048 and when frequency span is at maximum, all points are displayed. Once the FFT spectrum is displayed, the frequency span and center frequency controls are used much like the controls of a spectrum analyzer to examine the frequency of interest in greater detail. Place the desired part of the waveform at the center of the screen and decrease frequency span to increase the display resolution. As frequency span is decreased, the number of points shown is reduced, and the display is magnified.

## Making Measurements

### FFT Measurement

#### FFT Measurement Hints - Continued

While the FFT spectrum is displayed, use the **Math** and **Cursors** keys to switch between measurement functions and frequency domain controls in FFT menu.

Decreasing the effective sampling rate by selecting a slower sweep speed will increase the low frequency resolution of the FFT display and also increase the chance that an alias will be displayed. The resolution of the FFT is one-half of the effective sample rate divided by the number of points in the FFT. The actual resolution of the display will not be this fine as the shape of the window will be the actual limiting factor in the FFT's ability to resolve two closely spaced frequencies. A good way to test the ability of the FFT to resolve two closely spaced frequencies is to examine the sidebands of an amplitude modulated sine wave. For example, at 2 MSa/s effective sampling rate, a 1 MHz AM signal can be resolved to 2 kHz. Increasing the effective sampling rate to 4 MSa/s increases the resolution to 5 kHz for a set 2048 point FFT.

For the best vertical accuracy on peak measurements:

- Make sure the probe attenuation is set correctly. The probe attenuation is set from the Channel menu if the operand is a channel.
- Set the source sensitivity so that the input signal is near full screen, but not clipped.
- Use the Flat Top window.
- Set the FFT sensitivity to a sensitive range, such as 2 dB/division.

For best frequency accuracy on peaks:

- Use the Hanning window.
- Use Cursors to place an X cursor on the frequency of interest.
- Adjust frequency span for better cursor placement.
- Return to the Cursors menu to fine tune the X cursor.

For more information on the use of window please refer to Agilent Application Note 243, "The Fundamentals of Signal Analysis" Chapter III, Section 5 (Agilent part number 5952-8898.) Additional information can be obtained from "Spectrum and Network Measurements" by Robert A. Witte, in Chapter 4 (Agilent part number 5960-5718).